Development of Sign Language Interpreter Glove for Speech-Impaired Deaf Individuals with Levenshtein Algorithm as an Auto-Text Correction System.

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***Abstract*—Assistive technology refers to technology developed in the form of aids, adaptive tools, and rehabilitation for individuals with disabilities to compensate for their lacking abilities. With assistive technology available to people with special needs, it can help them enhance their independent living skills and reduce their dependence on others, including in communication activities. This research aims to assess the feasibility of developing assistive technology for the speech-impaired, specifically a glove that can translate the SIBI letter sequence into words displayed on a 6 x 12 LCD screen and also produce sound output from the sign language hand movements of speech-impaired individuals when using the glove. The research method used in this study is Research and Development (R&D). The calibration test phase indicated that the prototype was in good condition, as evidenced by an accuracy rate above 90% for voltage at 0° and 90° angles produced by each finger. Consequently, the next calibration phase, which involves translating sensor readings into SIBI letters through digital data values, can be carried out by taking the ADC values of each finger. Subsequently, the glove was tested to read 7 out of 20 alphabets and achieved a success rate of ≥ 90% for 5 alphabets. The lowest success rate was 70% for the letter E. The average success rate for the 7 alphabet experiments was 91.4%. In the field test phase, the glove was tested on a deaf-mute student to form several words, and the output text displayed on the LCD and audio output matched the readings corrected by the auto-text correction system.**

***Keywords*—Leveinshtein Algorithm, SIBI Letter,Smart Glove, Assistive Technology, Auto-text Correction**

I. INTRODUCTION

Individuals with disabilities or people with special needs constitute a community with unique and distinct characteristics and types [1],[2]. When someone has special needs, their condition inevitably has different characteristics or traits. Deaf-mute (*tunarungu wicara*) is one of the special needs still commonly found in Indonesia. Deaf-mute refers to an impairment in one of the senses that causes a child to have difficulty with verbal communication[3]–[5]. It is characterized by speech difficulties, a high-pitched voice, and frequent word repetition [6],[7]. On the other hand, individuals with deafness disabilities (*disabilitas tunarungu*) are those who have hearing impairments, which often lead to speech difficulties as well[8]. The communication method for individuals with deaf-mute or deafness disabilities usually involves sign language, with finger-spelling being internationally recognized and different sign languages existing for each country. In their daily activities, they utilize adaptive equipment[9], [10]. These tools can range from simple technology to complex and modern devices.

Assistive technology is technology developed in the form of aids, adaptive tools, and rehabilitation for individuals with disabilities to compensate for their lacking abilities[11], [12]. Assistive technology comes in various forms, ranging from low-tech devices to advanced technological tools. The importance of assistive technology lies in bridging physical/mental gaps, enabling individuals to improve and develop skills related to Activities of Daily Living (ADL) or daily life activities. With assistive technology available to people with special needs, it can help them enhance their independent living skills, reducing their dependence on others. Assistive technology also plays a supportive role in educational or academic activities.

The presence of assistive technology is one of the contributions to the Sustainable Development Goals (SDGs). SDGs are a set of global goals established by the United Nations (UN) to achieve sustainable development worldwide by 2030. Assistive technology significantly contributes to the SDGs, especially those related to inclusion, improving the quality of life for all individuals, and equality for people with disabilities[13],[14]. It can be observed that with the availability of assistive technology, individuals with disabilities will find it easier to secure employment and gain access to healthcare services[15], education[16], including workplace inclusion facilities[17].

This research aims to assess the feasibility of the development of assistive technology for the speech-impaired/ The assistive technology, glove can translate the SIBI letter sequence into words displayed on a 6 x 12 LCD screen. It also can produce sound output from the sign language hand movements of speech-impaired individuals when using the glove. The development of the Smart Talking Gloves is expected to serve as an effective assistive technology for speech-impaired individuals to enhance their daily productivity by facilitating communication. Furthermore, the Smart Talking Gloves can also benefit individuals without disabilities in learning the SIBI alphabet used by speech-impaired individuals.

II. METHODS

A. *Research Design*

The research method used in this study is Research and Development (R&D). The research and development method is aimed at creating new products through the development process. According to Sugiyono (2011:407) [18], research and development is a research method used to produce specific products and determine the effectiveness of those products. One of the R&D research models commonly used is the model developed by Borg & Gall in 1983, which employs the waterfall approach Fig. 1. The Borg and Gall development model consists of 10 research stages, including: (1) research and information collection, (2) planning, (3) developing a preliminary product form, (4) preliminary field testing, (5) main product revision, (6) main field testing, (7) operational product revision, (8) operational field testing, (9) final product revision, (10) dissemination and implementation [19].

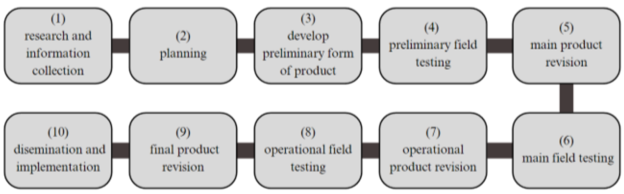

Fig 1. The Research and Development Model [20].

The product resulting from this research consists of hardware and software components. The hardware technology includes a glove developed to translate the sequence of SIBI letters using hand gesture movements for deaf-mute individuals (*tunarungu wicara*) to communicate with normal people. The software used to display the sensor readings is the 6x12 LCD screen.

The product development was carried out in the electrical power engineering laboratory and electronics laboratory. Testing was conducted at the home of one of the team members. Development involved collecting components such as flex sensors, gyroscope sensors, gloves, microcontrollers, and others. These components were then assembled into hardware that could be connected to the software by coding the microcontroller. Testing was conducted with a special education student from Sebelas Maret University in Surakarta, and it included calibration and validation test

In the information gathering phase, information was collected from various online sources to obtain details about SIBI letters and hand gestures, flex sensor calibration, analog-to-digital data translation, and flex sensor validation / main field test.

The planning phase included activities related to the preparation of a prototype development plan. It involved identifying and gathering tools and materials, categorizing them into hardware and software components. Hardware components included flex sensors, accelerometer-gyroscope sensors (MPU-6050), HC-05 modules, Arduino Nano, ESP32, and others. Software components included Arduino IDE, VS Code (Visual Studio Code), Eagle, Tinkercad, and XAMPP.

In the initial product development stage, a 3D design was created using Blender. After designing the 3D model, a diagram of the prototype development steps and a flowchart of the gloves system were developed. Mechanical design was also carried out, creating schematic diagrams for the circuit, microcontroller, and printed PCB.

During the development phase, the researcher assembled the components into hardware according to the schematic diagram and flowchart. The prototype's operation aligned with the established system flowchart. Product revisions were made to ensure the optimal functionality of the prototype. The study involved three stages of testing: calibration, functionality, and system testing.

Calibration aimed to improve accuracy and reduce sensor noise, determining basic finger movements. Two basic movements of the flex sensor were used: data values of voltage and resistance when the finger is flat and bent (0° and 90°). The calibration testing involved recording the maximum ADC values for each sensor on different fingers, verifying that the implemented system met the requirements of the designed and planned operational functions. System testing aimed to obtain parameters that demonstrate the capabilities and reliability of the entire system in executing its operational functions. This stage involved testing the reading of letters, word sequences, and audio output. Revisions were made whenever system performance was suboptimal or test results did not align with expectations. Revisions were repeated until the desired results were achieved. Main field testing was conducted after no further revisions were deemed necessary for the developed product.

B. *Design of a System*

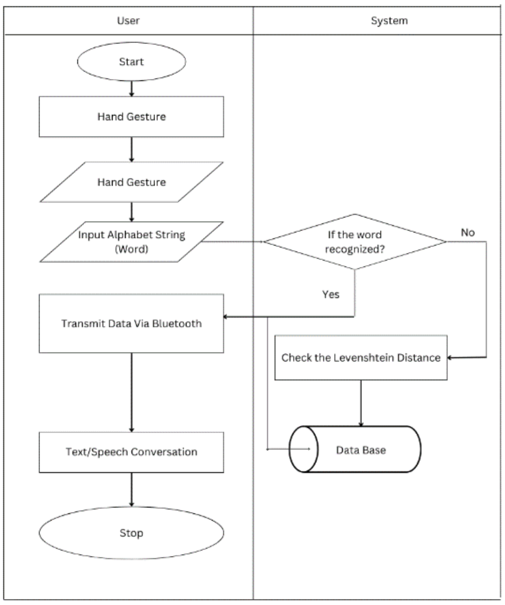

Fig 2. Design of the Auto-Text Correction System.

Based on Fig 2., the user wears the smart glove equipped with sensors on each finger. This glove is connected to the translation system that will process sign language gestures into text. The sensor data is sent to the system's processor, which analyzes the gesture patterns and matches them with stored data. The Levenshtein Distance algorithm is applied to compare the gesture input with words in the database. This algorithm measures the edit distance between the input and the words in the database, performing auto-text correction for any minor mistakes. After auto-text correction, the system searches the word database for the closest match. This database contains a list of words that can be used to generate accurate text from the sign language gestures. Then, the correct text is displayed on the 16 x 2 LCD screen. This screen shows the text corresponding to the sign language gestures performed by the user, enabling others to read the message conveyed.

C. *Components Requirement*

1) *Flex Sensor*

A flex sensor, also called bend sensor, measures the amount of deflection caused by bending the sensor. The sensor has two terminals – Power supply, V out. Developed from late 80s, there are three kinds of flex sensors[21]. Initially optical flex sensors were created and later conductive ink-based flex sensors [22] and capacitive flex sensors [23] were developed as alternates to prior, by different people. Resistance in these sensors is directly proportional to the. Optical flex sensors utilize a flexible tube with reflective interior walls, housing a light source at one end and a photosensitive detector at the other[24]. When the tube is bent, a combination of direct light rays is detected by the photosensitive detector, allowing measurement of deflection amount of bend produced in the sensor. Conductive ink-based flex sensors, on the other hand, consist of a phenolic resin substrate with conductive ink deposited on it. A segmented conductor is placed on top, forming a flexible potentiometer. The resistance of this sensor changes proportionally to the degree of deflection. Lastly, capacitive flex sensors employ two conductive layers of metals separated by a dielectric material. As the sensor is bent, the distance between the conductive layer changes, altering the capacitance and thus the resistance between them.

Fig 3. Flex Sensor 2,2 inch

2) *Accelerometer –Gyroscope Sensor (Internal MPU - 6050)*

The accelerometer sends X, Y, and Z acceleration forces. The forces are converted into X, Y, Z 3D angle to determine the 3D orientation of the sensor[25]. The interfacing of gyroscopic sensor with Arduino and liquid crystal display powered by 5V battery is done by soldering of jumper wires to the main controller board. Programming of the controller is developed in C++ language by using Arduino integrated development environment (IDE) software. The code is validated by performing trails subjected to various scenarios to achieve the precise measurement of the angle in different orientations. The sensor developed in this project can pave the way in various fields because of its ease of working and portability and user friendly nature. The MPU-6050 sensor integrates a 3-axis accelerometer and a 3-axis gyroscope, providing precise data on both acceleration and angular velocity [27],[28]. This combination allows for comprehensive motion tracking and orientation detection, which are essential for accurately interpreting hand movements in the context of sign language.

Fig 4. MPU 6050

3) *ESP 8266 Microcontroller*

The NodeMCU ESP8266 is an open-source microcontroller widely used for developing various prototype products based on the Internet of Things (IoT)[28]. In other words, NodeMCU is an IoT product development board based on eLua firmware and the ESP8266-12E System-on-Chip (SoC)[29]. ESP8266 itself is a WiFi chip with a complete TCP/IP protocol stack. To transmit programs or commands, the NodeMCU needs to be connected to a laptop using a USB cable. Code containing programs or commands is uploaded via the Arduino IDE software. This module is also equipped with WiFi for internet connectivity

Fig 5. Microcontroller ESP 8266

D. System Testing

1) Calibration Testing

In the first stage, calibration testing is conducted. Calibration is performed by comparing the output of the tested sensor with the theory measurement/standardized tools [30], so it is essential to ensure that the device can function properly [31]. The main purpose is to generate a baseline of sensor characteristics in the form of output voltage as a function of flex angle, providing a strong foundation for subsequently integrating ADC and adjusting its scale according to these results.

2) The Maximum and Minimum ADC Testing

Part of the calibration process involves recording ADC readings for maximum and minimum flex conditions, as well as accurately mapping the sensor reading range into the ADC scale[32].

3) SIBI Alphabet Output Testing

To test hand movements against 20 alphabets to determine the accuracy level of each alphabet.

4) Validation Test

The comprehensive testing of the translator system, auto-text correction, and audio output was carried out directly by the target users, forming several words.

III. Results and Discussion

The system developed includes two main inputs for the microcontroller: hand movements from users with hearing and speech impairments, and a word database. A flex sensor and an internal MPU-6050 accelerometer-gyroscope are utilized to read hand movements. The flex sensor is attached to each finger joint and experiences changes in resistance and voltage when bent, which are then mapped to corresponding letters. The gyroscope sensor reads hand orientation, which is crucial because some letters in the Indonesian Sign Language (SIBI) have similar movements but different orientations, allowing the system to differentiate the position of the palm. The word database operates using the Levenshtein distance algorithm, which helps find the correct word string in case of errors in word formation. The microcontroller processes the inputs from the hand movement sensors and the database, translating them into text displayed on an LCD screen and audio output, enabling non-disabled individuals to read and hear the words communicated by individuals with disabilities.

Fig 6. Design(a) Final Product (b)

A. Voltage and Resistance Value Testing on the Sensor

TABLE I. VOLTAGE AND RESISTANCE TESTING RESULT

Sensor	Testing Result				Measurement Theory			
	Voltage		Resistance		Voltage		Voltage Accuracy (%)	
	0°	90°	0° (k Ω)	90°	0°	90°	0°	90°
Thumb	2,02	2,55	34,25	54,07	2,11	2,67	96,73	93,63
Index Finger	1,96	2,82	32,52	65,00	2,14	2,90	91,53	97,24
Middle Finger	1,92	2,56	30,67	53,66	1,97	2,66	97,46	96,24
Ring Finger	1,84	2,50	29,57	54,14	1.93	2,67	95,33	93,63
Little Finger	2,17	2,91	38,27	64,30	2.24	2,88	96,87	99,31
Average	1,98	2,66	33,06	58,23	2,078	2,76	95,39	96,37

The calibration test phase aims to ensure that the measurements taken are accurate and consistent by comparing them with theory. Inconsistent measurement results will directly impact the product's quality. The voltage values on the flex sensor represent the changes in resistance due to bending. In theory, the electrical circuit to determine the voltage across one of the resistors in a series circuit can be obtained using a formula, as in equation (1).

$$V_{R\ flex\ sensor} = \frac{R_{flex\ sensor}}{R_1 + R_{sensor\ flex}} V_{cc} \quad \text{...........equation (1)}$$

Based on Table I, measurement results and theoretical calculations according to equation (1) were obtained, resulting in accuracy between the measurements and theoretical calculations with an average accuracy of 96% when the finger is bent at around 90°. The readings at 0° and 90° have different accuracy values. When the flex sensor is bent at 90°, it provides higher accuracy because at that point, the sensor is in a more significant bending position, and the sensor's sensitivity has decreased, making the readings more accurate. In contrast, at 0° position, the sensor has higher sensitivity, resulting in lower accuracy in the readings. The accuracy level for the readings of the five sensors is considered good because it approaches 1.

B. The Maximum and Minimum ADC Testing

Sensor data reading was performed by uploading the code from Arduino IDE to the microcontroller. Digital data in the form of ADC values were required to determine the SIBI letters read from the sensor readings. The experimentation on the prototype involved capturing the digital ADC data values for all five fingers to find the maximum and minimum ADC values for each finger. Since the calibration test phase indicated that the prototype was in good condition, the translation of sensor readings into SIBI letters through digital data values can be carried out. Data collection was done by repeatedly moving all five fingers from a straight position to 90°.

TABLE II. ADC TESTING RESULT

No	Thumb	Index Finger	Middle Finger	Ring Finger	Little Finger
1	607	610	615	626	550
2	607	603	610	620	550
3	607	605	612	624	552
4	608	607	613	623	547
5	609	602	609	621	548
6	607	605	612	621	553
7	609	606	611	621	555
8	608	613	614	624	558
9	607	610	613	625	558
10	606	604	609	620	552
MIN	606	602	609	620	547
MAX	609	613	615	626	558

From the five tested sensor data, maximum and minimum ADC values were obtained as shown in Table II. The maximum and minimum ADC values on the flex sensors are used as mappings in the Arduino design. The ADC sensor readings on the thumb and little finger tend to be low because they only have two bends.

C. SIBI Alphabet Output Testing Result

In the next test, a system test was conducted on hand gestures that produce ADC values, which were then translated into SIBI letter outputs. The purpose of this test is to further analyze whether the generated ADC values are accurate. Testing the accuracy of hand gestures involved using the 7 SIBI alphabet letters to determine the appropriate letter range. The range considered is the maximum and minimum boundaries of the ADC values obtained earlier.

TABLE III. SIBI ALPHABET OUTPUT TESTING

No.	Alphabet	Result										Percentage (%)
		1	2	3	4	5	6	7	8	9	10	
1.	A	A	A	A	A	A	A	A	A	A	A	100%
2.	B	B	B	B	B	B	B	B	B	B	B	100%
3.	C	C	C	C	C	C	C	C	C	C	O	90%
4.	D	D	D	D	D	D	D	D	D	D	D	100%
5.	E	*	E	E	E	E	E	*	E	*	E	70%
6.	F	F	F	F	F	F	F	F	F	F	F	100%
7.	G	L	G	G	G	L	G	G	G	G	G	80%
Average												91,40%

Table III. represents the experiment for letters A, B, D, and F resulted in a success rate of 100%. For letter C, a success rate of 90% was achieved. For letter G, the success rate was 80%. The lowest success rate was 70% for letter E. The average success rate for the 7 alphabet experiments is 91.40%.

D. Validation Test Result

The next testing phase involved testing word sequences by implementing the Levenshtein distance algorithm. The tested words are in the Indonesian language. In this study, we involved a research subject, a deaf mute student, to use the glove and move her fingers to form letters. Hand gestures based on SIBI letters are performed sequentially according to the desired word. The word sequence appears on the first line of the LCD screen. The second line of the LCD screen serves as an auto-text correction feature based on the input database. The purpose of this system test was to determine whether the Levenshtein distance algorithm can function optimally in correcting translated words.

TABLE IV. VALIDATION TEST RESULT

No.	Text-Correction						Documentation	Audio System
1.	C	A	C	-	N	G	 Fig 7. "CACING" word on LCD Screen	√work
	C	A	C	I	N	G		
2.	B	H	N	G	A		 Fig 8. "BUNGA" word on LCD Screen	√work
	B	U	N	G	A			
3.	L	O	K	E	-		 Fig 9. "LOKET" word on LCD Screen	√work
	L	O	K	E	T			
4.	G	L	O	K	A		 Fig 10. "GLOVA" word on LCD Screen	√work
	G	L	O	V	A			
5.	R	H	M	A	H		 Fig 11. "RUMAH" word on LCD Screen	√work
	R	U	M	A	H			

Table IV. shows that in some word combinations in Indonesia Language, there are errors in letter spelling, but the auto-text correction functions optimally to minimize errors when the word sequence appears on the LCD screen. Some tested words include "cacing" (worm), "bunga" (flower), "loket" (window), "glova," and "rumah" (house).

One of the words selected for the testing phase is "CACING". Hence, the manual computation analysis of Levenshtein distance between the strings "CAC-ING" and "CACING"[33]:

1. Initialization of the Matrix:
   The source string is "CAC-NG" (length 6), and the target string is "CACING" (length 6). The matrix d has dimensions (len(source) + 1) x (len(target) + 1), which is 7x7. 'Len' refers to the length of the strings

TABLE V. MATRIX INITIALIZATION

		C	A	C	I	N	G
	0	1	2	3	4	5	6
C	1						
A	2						
C	3						
-	4						
N	5						
G	6						

2. Base Cases:
   The first row and column represent the transformation from an empty string

TABLE VI. MATRIX INITIALIZATION

		C	A	C	I	N	G
	0	1	2	3	4	5	6
C	1	0	0	0	0	0	0
A	2	0	0	0	0	0	0
C	3	0	0	0	0	0	0
-	4	0	0	0	0	0	0
N	5	0	0	0	0	0	0
G	6	0	0	0	0	0	0

3. Matrix Filling:
   Iterating through the remaining cells of the array, filling in the values based on the minimum of three operations: insertion, deletion, or substitution.
   - For each cell \`(i, j)\`, if the characters at the positions \`i-1\` and \`j-1\` in the strings are equal, the value in the cell is equal to the value in the previous diagonal cell \`(i-1, j-1)\`.
   - Otherwise, it's the minimum of: The value in the cell above \`(i-1, j)\` plus 1 (deletion)
   - The value in the cell to the left \`(i, j-1)\` plus 1 (insertion)
   - The value in the previous diagonal cell \`(i-1, j-1)\` plus 1 (substitution)

TABLE VII. MATRIX FILLING COMPARING SOURCE ALPHABET TO TARGET CORRECTION

		C	A	C	I	N	G
	0	1	2	3	4	5	6
C	1	0	1	2	3	4	5
A	2	1	0	1	2	3	4
C	3	2	1	0	1	2	3
-	4	3	2	1	1	2	3
N	5	4	3	2	2	1	2
G	6	5	4	3	3	2	1

Table VII. shows The matrix d represents the costs of transforming substrings of "CAC-NG" into substrings of "CACING". The value in the bottom-right cell d [6][6] indicates the Levenshtein distance. The Levenshtein distance between "CAC-NG" and "CACING" is 1. This means one edit is required to transform "CAC-NG" into "CACING", which in this case is the substitution of the character ‘ - ‘ to be ‘I’ at the 4th position.

The manual computation is implemented in the Arduino IDE by coding the Levenshtein distance algorithm, with the input of the number of target word database according to the needs or frequently used words by the target user. The algorithm code for Arduino IDE can be seen in Fig 12.

```
// Strings to compare
  String source = "CAC-ING";
  String target = "CACING";

  // Compute Levenshtein distance
  int distance = levenshteinDistance(source, target);

  // Print the result
  Serial.print("The Levenshtein distance between '");
  Serial.print(source);
  Serial.print("' and '");
  Serial.print(target);
  Serial.print("' is ");
  Serial.println(distance);
}

void loop() {
  // Nothing to do here
}
```

```
// Function to compute Levenshtein distance
int levenshteinDistance(String source, String target) {
  int lenSource = source.length();
  int lenTarget = target.length();

  // Create a 2D array to store distances
  int d[lenSource + 1][lenTarget + 1];

  // Initialize the base cases
  for (int i = 0; i <= lenSource; i++) {
    d[i][0] = i;
  }
  for (int j = 0; j <= lenTarget; j++) {
    d[0][j] = j;
  }

  // Compute distances
  for (int i = 1; i <= lenSource; i++) {
    for (int j = 1; j <= lenTarget; j++) {
      int substitutionCost = (source[i - 1] == target[j - 1]) ? 0 : 1;

      d[i][j] = min(
        min(d[i - 1][j] + 1,     // Deletion
            d[i][j - 1] + 1),    // Insertion
        d[i - 1][j - 1] + substitutionCost  // Substitution
      );
    }
  }

  // Return the Levenshtein distance
  return d[lenSource][lenTarget];
}
```

Fig 12. Arduino IDE Algorithm of Levenshtein Distance

In the functional testing phase, testing of the audio system was also conducted. The purpose of this test is to determine if the word sequences read result in appropriate audio output. At each data collection interval, the body gesture is set to a neutral position, which means straightening all five fingers with slight spacing between each finger. The accuracy testing result of hand gestures with gesture transitions uses the neutral gesture with audio output that matches the readings corrected by the auto-text correction system.

IV. Conclusion

Based on the results of testing, system analysis, and discussions conducted, the following conclusions were obtained:

1. The flex sensor, accelerometer-gyroscope sensor (MPU-6050) can detect hand movements using a microcontroller, which processes the input values from those sensors and sends the data to a database.
2. Since the calibration test phase indicated that the prototype was in good condition, the translation of sensor readings into SIBI letters through digital data values can be carried out. The average success rate for the 7 alphabet experiments is 91.4%, with the highest success rate is 100% and the lowest success rate is 70%The validation testing result of hand gestures with gesture transitions using a neutral gesture with audio output is in accordance with the readings corrected by the auto-text correction system.

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